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MICROSTRUCTURE AND HARDNESS OF COPPER AFTER PRESSING BY ECAP

MIKROSTRUKTURA A TVRDOST MĚDI PO APLIKACI TECHNOLOGIE ECAP

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Abstract

Experiments were conducted in order to analyse the influence of equal-channel angular pressing (ECAP) on the microstructure and hardness of copper. The samples were processed by ECAP trough total of 14 passes at 20 °C using the processing route BC. The ECAP processing refines the grain size. The hardness increases with the number of passes, i.e. it increases with a decrease in the grain size.

Abstrakt

Experimenty byly provedeny za účelem vyhodnocení vlivu úhlového kanálového protlačování (ECAP) na mikrostrukturu a tvrdost mědi. Vzorky byly protlačovány technologií ECAP se 14 průchody při 20°C za použití technologické cesty BC. Při aplikaci technologie ECAP dochází ke zjemnění zrna. Se zvyšujícím se počtem průchodů se zvyšuje tvrdost materiálu a klesá velikost zrna.

Key words: microstructure, hardnes, ECAP, cooper

1. Introduction

Considerable improvement of mechanical properties of a material may be achieved by refinement of grains. New technologies of forming metals are based on the application of severe plastic deformation (SPD) to which belongs also equal-channel angular pressing (ECAP). In the ECAP processing a material is subjected to shear by pressing through an angular channel die. The principle of ECAP is described elsewhere [1, 2]. ECAP processing is also focused on refining of grains by SPD. Metallic materials are produced with ultrafine grains and they exhibit higher mechanical properties in comparison with their coarse-grained counterparts. A reduction of the mean grain size increases the yield stress and tensile strength of the material at room temperature according to the Hall-Petch relationship that predicts flow stress dependence on the reciprocal square root of the grain size. On the other hand, very small grains (typically about or less than 10 μm) promote superplastic properties of the material at a relatively high temperature (usually higher than 0.5 Tm, where Tm is the absolute melting temperature) at certain strain rates e.g.) [3, 4]. Processing by ECAP is at present very often used because it yields bulk samples without any change in the cross-section of the sample and without cavities (100 % dense). Suryanarayana [5] have claimed that ultrafine grained materials, with grain sizes between 100 and 1000 nm, have the greatest potential for industrial applications. Earlier investigations revealed that ECAP processing led not only to the production of ultrafine grains in polycrystalline metallic alloys but also to a very high total strain with a higher density of intragranular dislocations. Samples produced using ECAP may exhibit high strength at ambient temperatures and superplastic behaviour at higher temperatures. The deformation behaviour of a material after ECAP depends not only on the testing temperature but it may be influenced by conditions of ECAP processing as numbers of passes in ECAP and the temperature used in the ECAP processing.

The strength of materials depends on the grain size d according to the Hall-Petch relationship $\sigma_y = \sigma_0 + k_y d^{-1/2}$ where σ_0 is the friction stress and the value of k_y is specific to the material used. It is clear that fine grained materials have a higher yield strength than coarse-grained materials. Considering the polycrystals as a continuum, we can estimate the yield stress using the hardness test according to the relation $HV = 3\sigma_y$ where HV is the hardness.

The aim of the present work is to investigate the influence of the number of passes of ECAP on the microstructure and hardness of commercially pure copper. The chemical composition of the materials is given in Table 1.

Table 1 The chemical composition of Cu ČSN 42 3005 [wt. %]

Cu	Sn	As	O	Pb	Sb	Al	Fe	Se + Te	Bi
min. 99.5	max. 0.15	max. 0.10	max. 0.10	max. 0.10	max. 0.08	max. 0.05	max. 0.05	max. 0.03	max. 0.01

2. Experimental procedure

In the present work we used copper grade in accordance with the Czech standard ČSN 42 3005.Original samples were processed by cold forming and then annealed at a temperature of 870°C for 3 h. A square section of the samples was 8x8 mm. The details are described elsewhere [6]. The die used for the ECAP processing has two channels of equal cross section intersecting at an angle of $\Phi = 90°$. The ECAP processing produces a strain that was calculated using the relation

$$\varepsilon = \frac{2N}{\sqrt{3}} \cdot \cot g\left(\frac{\Phi}{2}\right) \quad (1),$$

where N is the number of passes. It means that each single pass lead to an imposed strain of about 1. Samples were processed by ECAP through total up to 14 passes using the processing route BC (each sample was rotated by 90° in the same sense between each pass) at room temperature. The ECAP device is described elsewhere [7].

The microstructures of the unprocessed and the as-processed samples were examined using a light microscope. The microstructure and hardness measurments were performed in the plane perpendicular to the pressing direction.

3. Experimental results and discussion

It was observed that the deformation strength increases after each single pass. An increase in the extrusion pressure was indicated. We tried to calculate the pressure needed for extrusion. The extrusion pressure at the beginning of ECAP was about $\sigma_1 = 658$ MPa. Extrusion pressures of $\sigma_2 = 965$ MPa and at the third extrusion it increased to $\sigma_3 = 1188$ MPa were determined at the second and the third extrusion pass, respectively [8]. The increase observed in the pressure needed for extrusion of samples with constant dimensions clearly indicates an increase of the strength (deformation resistance). An extrusion strain rate of about 2.3×10^{-2} s^{-1} was approximately determined.

The microstructures of original samples and that of samples after different passes are shown in Fig. 1. It is apparent that the grains have become significantly refined after each pass of ECAP. Some of the grains are elongated in the extrusion direction. The grain sizes of samples processed through 9 or 12 passes of ECAP are significantly smaller than after 1 or 2 passes.

The average grain size in the transverse direction determined by quantitative metallographic methods varied from about 50 μm at the beginning of extrusion to about 15 μm after the 4th pass.

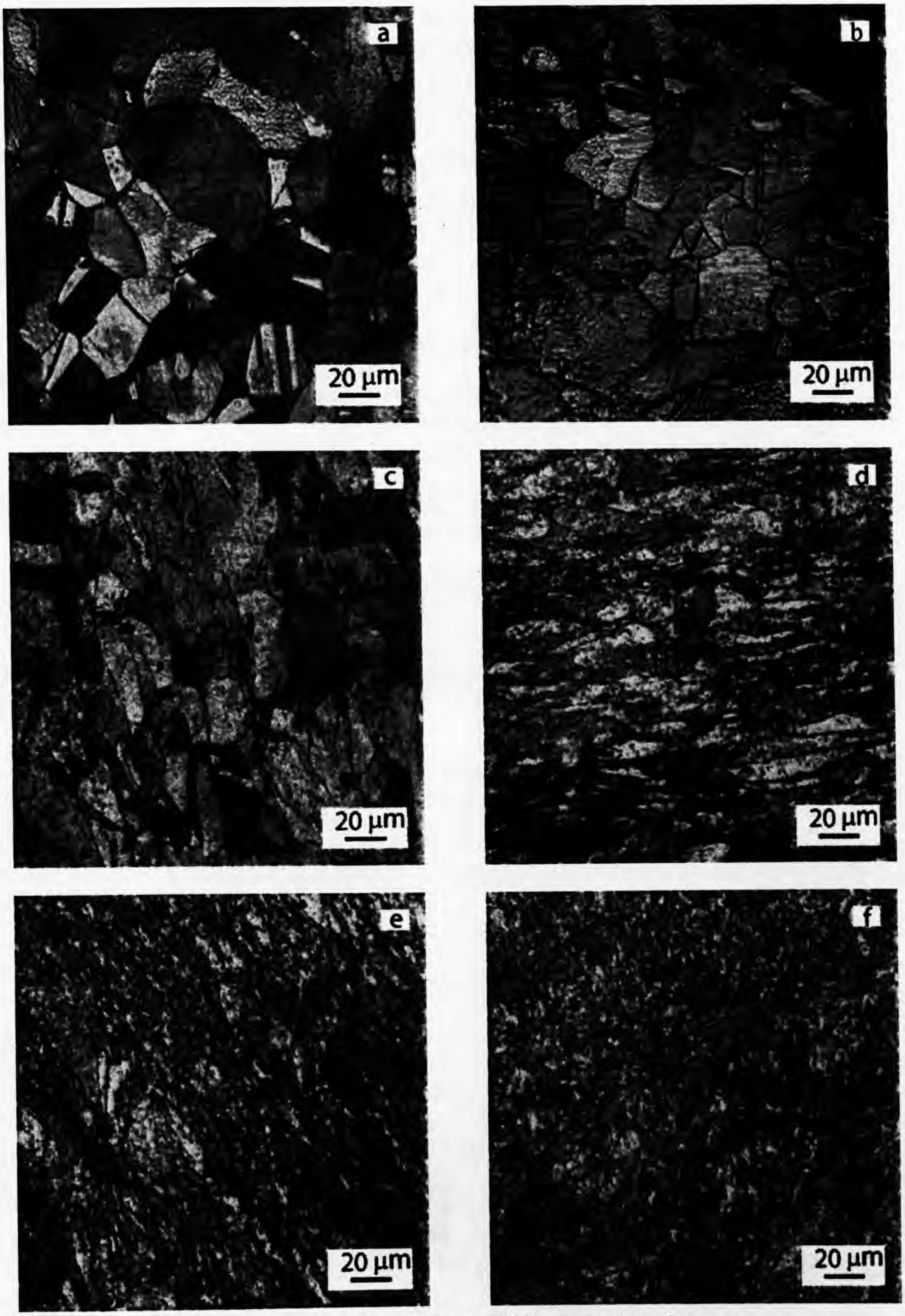

Fig. 1 Development of structure at ECAP extrusion of copper:

a) initial structure , b) structure after the 1st extrusion, c) structure after the 3th extrusion, d) structure after the 5th extrusion, e) structure after 6th extrusion and f) after 8th extrusion

The hardness, HV, depends on the number of passes through a die. The values are presented in Fig. 2 as a function of the number of passes of ECAP. The variation of the hardness with the passes number N may be expressed by a relation

$$HV = 116.3 + 13.7 \ln N \quad (2)$$

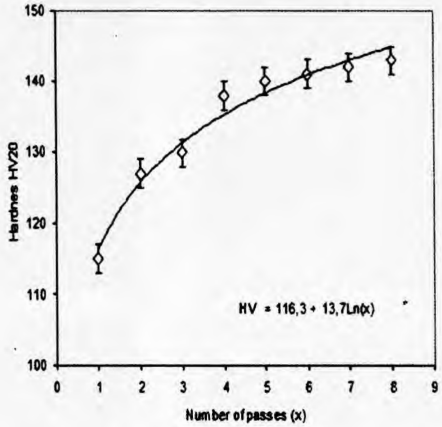

Fig. 2 Hardness of individual samples after extrusion

4. Conclusions

Experiments made on poly-crystalline copper of the grade 42 3005 have confirmed that the ECAP method is efficient tool for refining of grain. This process enabled obtaining a grain size of about. 15 μm.

The microstructure depends on ECAP conditions, particularly on the number of passes and on rotation of the sample between individual passes.

Convenient angle between horizontal and vertical part of extrusive channel is around 90°. Radii of rounding of working parts of extrusive channel must correspond to conditions for laminar flow of metal.

Acknowledgements

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